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AN ANNOTATED BIBLIOGRAPHY OF HEAT TOLERANCE: REGARDING GENDER DIFFERENCES

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AN ANNOTATED 'IBLIOGRAPHY OF HEAT TOLERANCE:

REGARDING GENDER DIFFERENCES

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KEY TO ABBREVIATIONS

A_D-Body Surface Area
BHC-Body Heat Content
BP-Blood Pressure
C-Convective Heat Transfer
Cl^--Chloride Ion
DBP-Diastolic Blood Pressure
E-Evaporative Heat Transfer
E_{max}-Maximum Evaporative Heat Transfer
H-Metabolic Heat Production
HR-Heart Rate
HS-Heat Storage
HTT-Heat Tolerance Test
K^+-Potassium Ion
$kcal \cdot m^{-2} \cdot h^{-1}$-Kilocalories per square meter per hour
$kj \cdot kg^{-1}$-Kilojoules per kilogram
$km \cdot h^{-1}$-Kilometers per hour
$m \cdot min^{-1}$-Meters per minute
$ml \cdot kg^{-1} \cdot min^{-1}$-Milliliter per kilogram per minute
$\dot{m}_{sw}$-Sweat Rate, local site
M_{sw}-Sweat Rate, whole body
Na^+-Sodium Ion
O_2 pulse-Oxygen Pulse
P_{H2O}-Water Vapor Pressure
PV-Plasma Volume
$\dot{Q}$-Cardiac Output
R-Radiant Heat Exchange
rh-Relative Humidity
SBP-Systolic Blood Pressure
SGA-Sweat Gland Activation
SGF-Sweat Gland Flow
SR-Sweat Rate
SSEN-Sweat Sensitivity ($SR/\Delta T_{re}$)
SV-Stroke Volume
T_a-Ambient Temperature
T_{db}-Dry Bulb Temperature
T_{es}-Esophageal Temperature
$\bar{T}_b$-Mean Body Temperature
$\bar{T}_{sk}$-Mean Skin Temperature
T_{or}-Oral Temperature
T_{re}-Rectal Temperature
T_{sk}-Skin Temperature, local site
T_{ty}-Tympanic Temperature
T_{wb}-Wet Bulb Temperature
$\dot{V}_E$-Minute Ventilation
$\dot{V}O_2$-Oxygen Consumption
$\dot{V}O_2max$-Maximum Oxygen Consumption

INTRODUCTION

The Presidential Commission on the Assignment of Women in the Armed Forces has recommended the military adopt a gender-neutral assignment policy. To ensure occupational safety and military readiness, the Commission suggested that fitness requirements be developed for specialties that necessitate immoderate physical strength or cardiovascular capacity. Although fitness requirements have not yet been adopted, women in the military are performing physically demanding jobs. Sometimes, military women perform heavy work exacerbated by heat stress. It is a concern that work levels and heat exposures that are deemed appropriate for military men are equally appropriate for military women. Current occupation safety guidelines for physical activity in thermal extremes is a result of research conducted on males. Thus, the guidelines may not offer appropriate protection from thermal injury for females.

The purpose of this technical report is to provide an overview of the literature on the similarities and differences between men and women in their physiological responses to heat stress. Studies that compare thermoregulation in physically fit and sedentary females, as well as research examining the effect of the menstrual cycle on thermal physiology, are included. For each study reviewed, a brief synopsis of the methodology and a summary of relevant results are provided. It was the intent of this report to provide a literature resource, not a review paper, regarding gender differences in thermoregulation during heat exposure.

The studies reviewed in this paper were found by performing a computer literature search, from the year indicated to 1992, in various databases including: Occupational Safety and Health (1973), Biological Abstracts (1969), Medline (1985), and technical reports (1960). Key words used for the search were: female, women, thermal stress, thermal strain, and thermal physiology.

UNACCLIMATED MALES AND FEMALES AT REST

Fox, R. H., Löfstedt, B. E., Woodward, P. M., Eriksson, E., & Werkstrom, B. (1969). Comparison of thermoregulatory function in men and women. Journal of Applied Physiology, 26 (4), 444-453.

Protocol

Twenty-one women ($\dot{V}O_2max = 35.0$ ml·kg^{-1}·min^{-1}) and 21 men ($\dot{V}O_2max = 45.6$ ml·kg^{-1}·min^{-1}) completed a resting heat tolerance test. The test consisted of four phases: (1) neutral climate at 30°C for 30 min, (2) slow heating to 45°C, (3) fast heating to 55°C, and (4) controlled hyperthermia at 36°C for 75 min. During each phase M_{sw}, HR, T_{re}, and $\bar{T}_{sk}$ were measured.

Results

There was a significant difference in $\bar{T}_{sk}$ and T_{re} at onset of sweating between men and women; females began to sweat at a higher core temperature than the males. HR during the controlled hyperthermia stage of the test (Phase 4) was higher in the females than the males. From Phase 1 to Phase 4 of the heat exposure, H increased the same percent above resting value in both sexes, but the absolute increase in H was smaller in the females (3.74 kcal·m^{-2}·h^{-1}) compared to the males (5.07 kcal·m^{-2}·h^{-1}).

Grucza, R., Lecroart, J. L., Hauser, J. J., & Houdas, Y. (1985). Dynamics of sweating in men and women during passive heating. European Journal of Applied Physiology, 54, 309-314.

Protocol

Eight men and eight women, all heat unacclimatized, rested in a hot-dry environment (40°C T_{db}, rh 30%) for 60 min. T_{re}, $\bar{T}_{sk}$, M_{sw}, and $\dot{m}_{sw}$ were measured.

Results

The rates of rise in $\bar{T}_{sk}$ and T_{re} were greater in the women than the men. In addition, final T_r was slightly higher in the women than the men. However, the differences in percent increase and

maximum level attained for T_{re} and $\bar{T}_{sk}$ were not statistically different. When both these variables were factored together in the equation for $\bar{T}_b$ ($\bar{T}_b = 0.8T_{re} + 0.2\bar{T}_{sk}$), values for the women were significantly higher than for the men. The delay in onset of sweating was greater in the women compared to the men. Apparently the delay in onset of sweating in women potentiated a greater increase in $\bar{T}_b$ compared to the men. However, the difference in $\bar{T}_b$ was less pronounced than the difference in M_{sw} between the men and women. Thus, thermoregulation in women was characterized by a better equilibrium between HS and body fluid loss as compared to the men.

SUMMARY TABLE 1:
UNACCLIMATED MALES & FEMALES AT REST

Authors	M/F	Exp Design	Metabolic Rate	Climate Conditions	PV Loss	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Fox et al. 1969	21/21	75 min	rest	36°C T_{db}			=			<		$>T_{ty}$
Gruzca et al. 1985	8/8	60 min	rest	40°C/30% T_{db}/rh			>	=		<	=	>Time

All values are expressed as women compared to men.

Key to symbols: (=) equal to
(>) greater than
(<) less than

UNACCLIMATED FEMALES AND MALES AT AN ABSOLUTE WORK RATE

Morimoto, T., Slabochova, Z., Naman, R., & Sargent II, F. (1967). Sex differences in physiological reactions to thermal stress. Journal of Applied Physiology, 22 (3), 526-532.

Protocol

A total of 11 men and 12 women participated in this two-protocol study and none were acclimated to the heat. In Protocol I, five men and five women completed six HTTs, one test per week. Dry bulb temperature for these HTTs increased on subsequent tests, ranging from, 36°C to 49°C, and rh was low and constant at 30%. In Protocol II, eight men and eight women completed six HTTs, one test every 2 weeks. Dry bulb temperature was increased on subsequent tests, ranging from 33°C to 38°C, and rh was high and constant at 81%. In both protocols, the subjects rested for 30 min in the chamber, walked on a level treadmill (5.6 $km \cdot h^{-1}$) for 30 min, and then rested an additional hour. M_{sw}, sweat Cl^-, SGA, T_{re}, forearm T_{sk}, HR, and BP were measured.

Results

M_{sw} for men and women was not different in the dry heat (Protocol I), but in the humid heat (Protocol II), M_{sw} was greater in the men. In men, in subsequent heat exposures, as ambient temperature increased, M_{sw} and the concentration of Cl^- in sweat increased. Conversely, in women Cl^- concentration in sweat did not increase in successively hotter ambient temperatures. When Cl^- concentration in sweat was related to M_{sw}, women had a higher concentration compared to the men. In women, the maximum SGA was reached at lower T_{db} and rh, compared to men. However, the number of glands activated did not differ between the two sexes in either environment. Thus, to achieve a greater M_{sw} with an equivalent number of SGA, the men experienced a greater sweat flow rate through the activated sweat glands compared to the women. The slope of the rise in T_{re}, final T_{re}, or forearm T_{sk} were not different between the groups in either phase of the study.

Tsuzuki, K., Tochihara, Y., & Ohnaka, T. (1992). Effects of age and sex differences on physiological responses during exercise in different ambient temperatures. In W. Lotens and G. Havenith (Eds.), Proceedings of the Fifth International Conference on Environmental Ergonomics. 2-6 Nov, pp. 114-115.

Protocol

Six males ($\dot{V}O_2max$ = 55.9 $ml \cdot kg^{-1} \cdot min^{-1}$) and six females ($\dot{V}O_2max$ = 45.9 $ml \cdot kg^{-1} \cdot min^{-1}$) completed exercise tests at various temperatures (15°C, 25°C, and 35°C T_{db}, rh 50%). The test consisted of 15 min of rest between two 30-min exercise periods, requiring cycle ergometry at progressive work loads of 25 Watts, 50 Watts, and 75 Watts. Each exercise intensity was maintained for 10 min.

Results

At 35°C, T_{re} and HR were higher in the females than the males. At all three environmental temperatures, SBP was lower in the female group. The men had a higher ratio of SBP to HR than the women in all conditions, indicating the males had a larger circulating blood volume than the females.

SUMMARY TABLE 2:
UNACCLIMATED FEMALES & MALES AT AN ABSOLUTE WORK RATE

Authors	M/F	Exp Design	Metabolic Rate	Climate Conditions	PV Loss	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Morimoto	5/5	30/30/60	rest/ex	I36-49/30		=	=	=	=			
et al. 1967	8/8	120 min	5.6 km•hr^{-1}	II33-38/81			<	=	=	<		
			/rest	T_{db}°C/rh%								
Tsuzuki	6/6	15/30	rest/ex	I 15°C/50%			=	<	>			
et al. 1992		90 min		II 25°C/50%			=	=	>			
				III 35°C/50%			>	=	>			
				T_a°C/rh%								

All values are expressed as women compared to men.

Key to symbols: (=) equal to
(>) greater than
(<) less than

UNACCLIMATED MALES AND FEMALES AT A RELATIVE WORK RATE

Havenith, G., van Middendorp, H. (1990). The relative influence of physical fitness, acclimatization state, anthropometric measures and gender on individual reactions to heat stress. European Journal of Applied Physiology and Occupational Physiology, 61, 419-427.

Protocol

Twelve males and 12 females ($\dot{V}O_2max$ = 55.4 and 53.5 ml·kg^{-1}(lean body mass)·min^{-1}, respectively) participated in tests at three climates: neutral (21°C T_{db}, 50% rh), warm-humid (34°C T_{db}, 80% rh), and hot-dry (45°C T_{db}, 20% rh). The test was divided into three 30-min periods consisting of resting, light cycling (25% $\dot{V}O_2max$), and moderate cycling (45% $\dot{V}O_2max$).

Results

The physiological variables that had the largest influence on heat storage were percentage of body fat, surface area to mass ratio, and $\dot{V}O_2max$. $\bar{T}_{sk}$ was influenced primarily by ambient temperature, P_{H2O} and metabolic rate accounting for 96% of the variance. Thus, $\bar{T}_{sk}$ showed more dependence on the protocol than on the individual. On the other hand, T_{re} was influenced by both environmental and physiological variables. Of these physiological variables, percent fat, surface area to mass ratio, SSEN, and $\dot{V}O_2max$ together accounted for 22% of the variance. Heart rate variability was explained by climate, H (together 75%), and $\dot{V}O_2max$ (an additional 13%). A significant gender effect was shown but could be eliminated by accounting for percentage fat, surface area to mass ratio and $\dot{V}O_2max$ differences.

Paolone, A. M., Wells, C. L., & Kelly, G. T. (1978). Sexual variations in thermoregulation during heat stress. Aviation Space and Environmental Medicine, 49 (5), 715-719.

Protocol

Four men ($\dot{V}O_2max$ = 54 ml·kg^{-1}·min^{-1}) and three women ($\dot{V}O_2max$ = 48 ml·kg^{-1}·min^{-1}), who were physically fit but unacclimated to the heat, underwent three 2-hr HTTs in different thermal environments: 25/18°C $T_{db/wb}$, 32/24°C $T_{db/wb}$, and 40/31°C $T_{db/wb}$. During each exposure, the

subjects rested for 40 min, walked for 40 min at 50% of $\dot{V}O_2max$, then recovered for 40 min.

Results

In the neutral environment, the women had a lower M_{sw}, $\bar{T}_{sk}$, and HR, but a higher T_{re} than the men. In the hot environments, the women had lower T_{re}, M_{sw}, $\bar{T}_{sk}$, and HR than the men. In all three conditions, mean $\dot{V}O_2$ was greater in the males than in the females. SSEN was greater in the men than in the women; thus, men lost more body water per unit increase in core temperature compared to the women. For the women, exercise in the heat potentiated a greater increase in HR relative to the increase in metabolic cost ($\dot{V}O_2$) compared to the men. This lowered O_2 pulse ($HR/\dot{V}O_2$) in the hot environment suggests that the cardiovascular component of thermoregulation was taxed to a greater extent in the females than in the males.

Yousef, M., Dill, D., Vitez, T., Hillyard, S., & Goldman, A. (1984). Thermoregulatory responses to desert heat: age, race and sex. Journal of Gerontology, 39 (4), 406-414.

Protocol

Fifty-seven men and 60 women walked at 40% of $\dot{V}O_2max$ for 1 hr in the desert heat. The environmental conditions were not reported by the authors; although, a two-way analysis of variance was used to eliminate the effect of variations in ambient temperature on M_{sw}.

Results

At walk rates of 80 and 100 m/min HR, $\bar{T}_{sk}$ and T_{re} were higher and M_{sw} was lower in the women compared to the men.

SUMMARY TABLE 3:
UNACCLIMATED MALES & FEMALES AT A RELATIVE WORK RATE

Authors	M/F	Exp Design	Metabolic Rate	Climate Conditions	PV Loss	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Havenith et al. 1990	12/12	30/30/30 90 min	rest/ 25%VO_2max/ 45%VO_2max	I-21/50 II-34/80 III-45/20 T_{db}°C/rh%								
Paolone et al. 1978	4/3	40/40/40 120 min	rest/ 50%VO_2max/ recovery	I-25/18	<		>	<	<	<		
				II-32/24	<		<	<	<	<		
				III-40/31 T_a°C/T_{wb}	<		=	<	<	<		
Yousef et al. 1984	57/60	60 min	40% VO_2max	desert heat			>	>	>	<		

All values are expressed as women compared to men.

Key to symbols: (=) equal to
(>) greater than
(<) less than

ACTIVE ACCLIMATION IN FEMALES, AND FEMALES VERSUS MALES

Hertig, B. A., Belding, H. S., Kraning, K. K., Batterton, D. L., Smith C. R., & Sargent II, F. (1963). Artificial acclimation of women to heat. Journal of Applied Physiology, 18 (2), 383-386.

Protocol

Five women underwent 10 days of acclimation consisting of a 2-hr level treadmill walk at 4.8 $km \cdot h^{-1}$ in a hot environment (45/26°C $T_{db/wb}$). Four of the five women walked on a level treadmill at 5.6 $km \cdot h^{-1}$ in a hot climate (41/30°C $T_{db/wb}$) for ten 2-hr exposures. In each case, walking was interrupted at 30, 60, and 100 min of the test, with 10 min of rest. In both protocols, T_{re}, $\bar{T}_{sk}$, SGA, M_{sw} and $\dot{m}_{sw}$ were measured. Sweat Cl^- concentration was measured in samples collected from a plastic bag that encased the forearm.

Results

Results from each protocol demonstrate that on the last day of heat exposure, final measurements of T_{re}, HR, and $\bar{T}_{sk}$ were lower compared to the first day of the test. In addition, M_{sw} was greater on the final day of testing than on the initial day. These physiological changes are indicative of heat acclimation.

Horstman, D. H., & Christensen, E. (1982). Acclimatization to dry heat: Active men vs. active women. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 52 (4), 825-831.

Protocol

Six men ($\dot{V}O_2max$ = 51.4 $ml \cdot kg^{-1} \cdot min^{-1}$) and four women ($\dot{V}O_2max$ = 47.2 $ml \cdot kg^{-1} \cdot min^{-1}$) were tested before, after 6 days, and after 11 days of heat acclimation. The acclimation procedure consisted of cycling at 40% of $\dot{V}O_2max$ in a hot-dry environment (45/23°C $T_{db/wb}$) for 2 hr.

Results

At the time of the pretest, there was no gender difference in stay time, change in T_{re}, SSEN, or $\dot{Q}$. The men had a greater SR than the women, and the women had a higher HR than the men. On the sixth day of acclimation, the female group had less of a rise in T_{re}, greater SSEN, and a longer stay time than the male group. However, the males still had a greater SR compared to the females. $\dot{Q}$ and HR were not different between the sexes. Thus, the women had substantially decreased their HR and increased their SV, to maintain $\dot{Q}$ after 6 days of acclimation.

The gender differences evident on the sixth day of acclimation persisted through the eleventh day of heat exposures. After 11 days of acclimation, the SR in the men increased to a greater extent compared to the women; whereas, the rise in T_{re} (final T_{re} - basal T_{re}) was greater in the men than in the women. The changes in SR and rise in T_{re} were such that SSEN was greater in the women compared to the men, after 11 days of acclimation. There was not a significant change in PV during acclimation, but the females had an increase in SV. The mechanism potentiating this cardiovascular enhancement was not elucidated.

Weinman, K. P., Slabochova, Z., Bernauer, E. M., Morimoto, T., & Sargent II, F. (1967). Reactions of men and women to repeated exposure to humid heat. Journal of Applied Physiology, 22 (3), 533-538.

Protocol

Five men and five women walked on a level treadmill at 5.6 km·h^{-1} for 4 hr, completing a 50/10 min work/rest cycle in a chamber in which environmental conditions were 34/32°C $T_{db/wb}$. The acclimation procedure was completed eight times on alternate days. T_{re}, mid-thigh T_{sk}, BP, HR, and M_{sw} were measured.

Results

The females had lower HR at rest and during exercise than the males. However, when HR during exercise was expressed as a percentage above the value at rest, the relative increase in HR was greater in the women. In both men and women, there was a slight downward trend in maximum values of HR over the 8 day acclimation period. On each test day, the female group

attained their maximum HR more rapidly than the male group. There was no difference between T_{re} and T_{sk} between the sexes on any test day. There was a slight but significant decrease in the rate of rise in T_{re} in the female group on subsequent test days. In this hot-moist environment, the M_{sw} was lower in the females than the males. During successive heat exposures, maximal M_{sw} increased in the male group. Although the females showed this same tendency, the difference in M_{sw} from day one to day eight was not statistically significant. The women were capable of accomplishing the same work task as the men, but had lower HR, M_{sw}, and T_{re}. Both groups exhibited signs of achieving some degree of acclimation.

SUMMARY TABLE 4:
ACTIVE ACCLIMATION IN FEMALES, AND FEMALES VERSUS MALES

Authors	M/F	Exp Design	Metabolic Rate	Climate Conditions		PV Loss	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Hertig et al. 1963	0/4	120 min 10 days	4.8km•hr^{-1}	45/26 T_{db}°C/rh%	*			>	>	>			
	0/4	120 min 10 days	5.6km•hr^{-1}	41/30 T_{db}°C/rh%	*			>	>	>			
Hortsman et al. 1985	6/4	120 min 11 days	40% VO_2max	45/23 T_{db}°C/rh%	§			<			<	>	
Weinman et al. 1967	5/5	50/10min 8 alt day	ex/rest 5.6 km•hr^{-1}	34/32 $T_{db/wb}$°C	§			=	=	<	<		

Key to symbols:
(=) equal to
(>) greater than
(<) less than
(*) Day 1 compared to Day 10, women compared to themselves
(§) Extent of change from Day 1 to Day 10, women compared to men

ACCLIMATED MALES AND FEMALES AT AN ABSOLUTE WORK RATE

Avellini, B., Shapiro, Y., Pandolf, K., Pimental, N., & Goldman, R. (1980). **Physiological responses of men and women to prolonged dry heat exposure.** Aviation, Space, & Environmental Medicine, 51 (10), 1081-1085.

Protocol

Nine women and ten men ($\dot{V}O_2max$ = 40.5 and 52.3 ml·kg^{-1}·min^{-1}, respectively) participated in a prolonged (4 hr) test in a hot-dry environment (49°C T_{db}, 20% rh) after completing 6 days of a 2-hr active acclimation protocol. During both acclimation and the HTT, the subjects alternated 10 min of rest with 50 min of a level treadmill walk at 1.34 m·s^{-1}

Results

In both men and women, acclimation elicited a drop in final T_{re} and HR, but did not elicit a change in M_{sw}. The final T_{re} during the 4 hr HTT was equivalent between the sexes. The women had a significantly higher HR at the end of each hour when compared to the men. The different HR responses reflect that the women were exercising at a higher relative workload than the men (36% vs. 29% of $\dot{V}O_2max$, respectively). Compared to the men, the women had 7% less heat gain via R + C, due in part to their higher $\bar{T}_{sk}$; and 16% less heat production via H, due to their lesser body mass. Whereas, the heat load potentiated a 7% greater M_{sw} (non-significant difference), and an 8% greater E in the men compared to the women. The result was that men and women stored heat at the same rate over the duration of the heat exposure.

Kamon, E., Avellini, B., & Krajewski, J. (1978). Physiological and biophysical limits to work in the heat for clothed men and women. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 44 (6), 918-925.

Protocol

Four acclimated men ($\dot{V}O_2max$ = 61.7 ml·kg^{-1}·min^{-1}) and four acclimated women ($\dot{V}O_2max$ = 39.9 ml·kg^{-1}·min^{-1}) walked on a treadmill, in seven ambient temperatures (36°C to 52°C). The

temperature and humidity were held constant for 1 hr. For up to 2 hr thereafter, the vapor pressure was progressively increased. The treadmill speed for the women (80.4 to 87.0 $m \cdot min^{-1}$) was slower than that for the men (93.6 $m \cdot min^{-1}$), but elevation was added to yield equivalent metabolic heat production ($\dot{V}O_2 \cdot L \cdot min^{-1} = 1.04$) in the men and the women. The work load for the men represented 25% of $\dot{V}O_2max$, and for the women represented 43% of $\dot{V}O_2max$.

Results

The T_{re} break point, the T_{re} after which core temperature rose steeply, was not different between the men and women. When results were averaged over the entire exposure, means for HR, $\bar{T}_{sk}$, and T_{re} were not different between the men and women. M_{sw} in the men was greater than in the women, the difference reaching significance at ambient temperatures greater than 44°C. Critical air vapor pressure, the ambient pressure prior to the point at which upward inflection of T_{re} occurred, tended to be lower in the females compared to the males. However, the difference was significant only for the 40°C condition.

Shapiro, Y., Pandolf, K. B., Avellini, B. A., Pimental, N. A., & Goldman, R. F. (1980). Physiological responses of men and women to humid and dry heat. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 49 (1), 1-8.

Protocol

Ten males ($\dot{V}O_2max = 52.3\ ml \cdot kg^{-1} \cdot min^{-1}$) and nine females ($\dot{V}O_2max = 40.5\ ml \cdot kg^{-1} \cdot min^{-1}$) were acclimatized to heat for 6 days by walking on a level treadmill at 80.4 $m \cdot min^{-1}$ for 2 hr in a hot-dry environment (49°C T_{db}, 20% rh). After acclimating, the subjects participated in six HTT in various environments: comfortable (20°C T_{db}, 40% rh), warm-humid (32°C T_{db}, 80% rh), hot-humid (35°C T_{db}, 90% RH; 37°C T_{db}, 80% rh), and hot-dry (49°C T_{db}, 20% rh; 54°C T_{db}, 10% rh). The 2-hr protocol consisted of walking on the treadmill twice at 80.4 $m \cdot min^{-1}$ for 50 min with a 10 min rest in between.

Results

In the comfortable environment there were no differences in variables measured between the men and the women. However, in the warm-humid environment, the female group had lower T_{re}, $\bar{T}_{sk}$, M_{sw}, and HS than the male group. In the hot-humid climate, these gender differences persisted. In addition, in this climate condition, the higher M_{sw} in the male group resulted in greater dehydration, when defined as a greater percent loss in body mass. Although the men sweated more, it did not translate to greater thermoregulation than in the women (evidenced by lower T_{re} and HS in the women). In the hot-dry environment, the sex differences were reversed. The men had lower T_{re}, HR, $\bar{T}_{sk}$, and HS compared to the women. Although M_{sw} was not different between the men and the women, the cardiovascular strain in the men was less evident, and evaporative cooling was more effective. Thus, the greater sweating capacity of the men was advantageous in environments in which E_{max} was large, but a disadvantage in those climates in which E_{max} was minimal.

Shapiro, Y., Pandolf, K., Avellini, B., Pimental, N., & Goldman, R. (1981). Heat balance and transfer in men and women exercising in hot-dry and hot-wet conditions. Ergonomics, 24 (5), 375-386.

Protocol

Ten males ($\dot{V}O_2max$ = 52.3 $ml \cdot kg^{-1} \cdot min^{-1}$) and nine females ($\dot{V}O_2max$ = 40.5 $ml \cdot kg^{-1} \cdot min^{-1}$) were acclimated to heat for 6 days by walking on a level treadmill at 80.4 $m \cdot min^{-1}$ for 2 hr in a hot-dry environment (49°C T_{db}, 20% rh). After acclimating, the subjects participated in six HTTs in various environments: comfortable (20°C T_{db}, 40% rh), warm-humid (32°C T_{db}, 80% rh), hot-humid (35°C T_{db}, 90% rh; 37°C T_{db}, 80% rh), and hot-dry (49°C T_{db}, 20% rh; 54°C T_{db}, 10% rh). The 2-hr HTT consisted of twice walking for 50 min at 80.4 $m \cdot min^{-1}$ and resting for 10 min.

Results

M_{sw} was not significantly different between the sexes in the hot-dry environments, but the females had a lower M_{sw} than the males in the hot-wet climates. These differences resulted in higher sweating efficiency for the women than for the men, in the hot-wet but not in the hot-dry

conditions. $\bar{T}_{sk}$ tended to be higher in the hot-dry environments and lower in the hot-wet environments, for the female group compared to the male group. Generally, the women had less heat gain from the environment (R + C), and less H compared to the men. Thus, E needed to maintain thermal equilibrium was smaller for the women than for the men. The females had a higher surface area to mass ratio compared to the males. The women had less heat gain per surface area than the men. Thus, in the hot-dry environments, the temperature gradient from skin to environment was less in the females compared to the males, and may have been responsible for the diminished heat gain for the females.

Shapiro, Y., Pandolf, K., & Goldman, R. (1980). Sex differences in acclimation to a hot-dry environment. Ergonomics, 23 (7), 635-642.

Protocol

Ten males ($\dot{V}O_2max$ = 52.3 $ml \cdot kg^{-1} \cdot min^{-1}$) and nine females ($\dot{V}O_2max$ = 40.5 $ml \cdot kg^{-1} \cdot min^{-1}$) were acclimated to heat for six consecutive days by walking on a level treadmill twice at 80.4 $m \cdot min^{-1}$ in a hot-dry environment (49°C T_{db}, 20% rh).

Results

H and M_{sw} were not different between the sexes, and remained unchanged throughout acclimation. T_{re} and $\bar{T}_{sk}$ were higher in the females compared to the males, both initially and after 6 days of heat exposure. T_{re} and $\bar{T}_{sk}$ declined from Day 1 to Day 4 of acclimation at equivalent rates in the males and females. The women tended to have a higher HR than the men, both before and after acclimation. Heat gain by R + C, as well as heat loss via E, did not change throughout the acclimation procedure in either sex; however, both R + C, and E were higher in the men compared to the women. The results indicated: (1) sex differences in heat tolerance were still evident after 6 days of acclimation, and (2) the rate of acclimation was equivalent between the sexes.

Wyndham, C. H., Morrison, J. F., & Williams, C. G. (1965). Heat reactions of male and female Caucasians. Journal of Applied Physiology, 20, 357-364.

Protocol

Thirty males and 26 females unacclimatized to the heat performed a step test ($\dot{V}O_2 = 1\ L \cdot min^{-1}$) for 4 hr in a hot-dry environment (34/32°C $T_{db/wb}$). Ten of the men and six of the women participated in an acclimation procedure, lasting 12 days for the men and 19 days for the women. Following acclimation, the men and women repeated the 4-hr step test. HR, T_{re}, and M_{sw} were measured.

Results

During the pretest, 92% of the women failed to complete the test, whereas 50% of the men failed to complete the test. The men and women had comparable T_{re} and HR upon withdrawing from the test; however, HR and T_{re} rose more rapidly in the females compared to the males. M_{sw} at each hour was higher in the males compared to the females, but the differences decreased over the duration of the test. The female group acclimated more slowly than the male group (19 vs. 12 days, respectively). After acclimation, final HR and T_{re} were not different between the sexes. During the posttest, M_{sw} in the males increased hourly, unlike during the pretest values, at which M_{sw} dropped during the third hour of testing. Posttest M_{sw} values increased from the pretest values in the women. However, the magnitude of the increase in M_{sw} for the females was not as great as for the males. Thus, the difference in M_{sw} between men and women was amplified after the acclimation procedure. However after acclimation, the lower M_{sw} in the females did not preclude them from attaining a comparable level of thermoregulation as in the males, evidenced by the equivalent T_{re}, HR, and stay time between the male and female groups.

SUMMARY TABLE 5
ACCLIMATED MALES & FEMALES AT AN ABSOLUTE WORK RATE

Authors	M/F	Exp Design	Metabolic Rate	Climate Conditions	PV Loss	HS	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Avellini et al. 1980	10/9	4 hr	1.34 $m \cdot s^{-1}$	49/20 T_{db}°C/rh%		=		=	>	>	=		
Kamon et al. 1978	4/4	3 hr	VO_2= 341 Watts	36-52 T_a°C				=	=	=	<		
Shapiro et al. 1980	10/9	50/10 120 min	ex/rest 1.34 $m \cdot s^{-1}$	I-neutral									
				II-hot-dry		>		>	>	>	=		
				III-hot-humid	<	<		<	<		<		
				IV-warm-humid		<		<	<		<		
Shapiro et al. 1981	10/9	50/10 120 min	ex/rest 1.34 $m \cdot s^{-1}$	I-neutral									
				II-hot-dry						>			
				III-hot-humid							<		
				IV-warm-humid					<				
Shapiro et al. 1980	10/9	50/10 120 min	ex/rest 1.34 $m \cdot s^{-1}$	49/20 T_{db}°C/rh%				>	>	>	=		
Wyndham et al. 1965	10/6	4 hr	1 $l \cdot min^{-1}$	34/32 $T_{db/wb}$°C				=		=	<		

All values are expressed as women compared to men.

Key to symbols (=) equal to
(>) greater than
(<) less than

ACCLIMATED FEMALES AND MALES AT A RELATIVE WORK RATE

Avellini, B. A., Kamon, E., & Krajewski, J. T. (1980). Physiological responses of physically fit men and women to acclimation to humid heat. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 49 (2), 254-261.

Protocol

Four men and four women with similar aerobic capacities (57.0 and 52.5 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) and equal A_D, walked on a treadmill at 5.6 $km \cdot h^{-1}$ and 2% grade (work load = 30% $\dot{V}O_2max$) in the heat (36/30°C $T_{db/wb}$) for up to 3 hr. The test protocol was repeated after the subjects completed 10 days of acclimation. The acclimation protocol consisted of 2 hr of treadmill walking (work load = 30% $\dot{V}O_2max$) at 36/32 °C $T_{db/wb}$. The women were tested both in the follicular and the luteal phase of their menstrual cycles (determined by changes in T_{or}).

Results

Before acclimation, the women in the follicular phase of their menstrual cycles had longer stay times than when they were in the luteal phase, as well as longer stay times than the men. In addition, both the follicular and luteal phase groups had lower HR and T_{re} than the male group during the 3-hr exposure. However, when HR was expressed as percent change from resting values, the men and women had equivalent increases. The difference in M_{sw} between the women at the two different phases was not significant. In the men, M_{sw} was higher than in both groups of women at the 30- and 60-min measurements. However at 90-min, M_{sw} in the men declined to levels equivalent to that in the females. After acclimation, M_{sw} in the males increased proportionately more than increases shown by both the follicular and luteal phase groups of women (+35% vs. +15% and +18%, respectively). Thus, acclimation served to magnify this gender difference. After acclimation, the M_{sw} of the male group was 42% greater than in the follicular-phase females and 50% greater than in the luteal-phase females. T_{re} at sweat onset was not different between any of the groups, before or after acclimation. During the posttest, T_{re}, $\bar{T}_{sk}$, and HR were identical in all three groups, until min 90. After 90 min of heat exposure, HR and T_{re} increased at a greater rate in the men than in either group of women.

Dill, D. B., Soholt, L. F., McLean, D. C., Drost, T. F., & Loughran, M. T. (1977). Capacity of young males and females for running in desert heat. Medicine and Science in Sports and Exercise, 9 (3), 137-142.

Protocol

Fourteen males ($\dot{V}O_2max$ = 54 ml·kg^{-1}·min^{-1}) and 12 females ($\dot{V}O_2max$ = 37 ml·kg^{-1}·min^{-1}) completed a 1 hr walk/run session in the desert heat (32°C to 47°C T_a). The first test was at a pace of 80 m·min^{-1}. The rate of the walk was increased by 20 m·min^{-1} during subsequent tests until the pace could not be maintained for 1 hr. Maximal pace was reached after an average of five tests in the men and three tests in the women.

Results

The maximum walk rate attained by the male group (160 m·min^{-1}) was faster than that attained by the female group (120 m·min^{-1}). During this final test, H was increased sixfold to eightfold for the men and threefold to fivefold for the women. The maximal effort elicited equivalent HR, $\bar{T}_{sk}$, and T_{re} in the male and female subjects. However, SR was greater in the males than the females. This was most likely due to the greater metabolic heat production in the males. When group results were compared at the 100 m/min rate, there was no gender difference in $\dot{V}O_2$ or SR.

Frye, A. J., & Kamon, E. (1981). Responses to dry heat of men and women with similar aerobic capacities. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 50 (1), 65-70.

Protocol

Four women and four men with similar aerobic capabilities (54.1 and 56.3 ml·kg^{-1}·min^{-1}, respectively) exercised at 30% of $\dot{V}O_2max$ in a hot-dry environment (48/25°C $T_{db/wb}$) for up to 3 hr before and after heat acclimation. The subjects were considered acclimated if their T_{re} and HR leveled off on two consecutive days during a 2-hr bout of exercise (25% to 30% $\dot{V}O_2max$) in a hot-dry climate (48/25°C $T_{db/wb}$). Most subjects were acclimated after 8 to 9 days. The

women completed two HTT before and two HTT after acclimation, during the follicular and luteal phases of their menstrual cycle.

Results

There were no differences in measured variables between the tests during the two phases of the menstrual cycle either before or after acclimation. Prior to acclimation, the men had a longer stay time, lower T_{re}, and lower HR. There was no sex difference in SSEN or threshold T_{re} at sweat onset. After acclimation no differences were detected between the groups. During the postacclimation test, both groups experienced a decrease in T_{re} and HR with a concomitant increase in M_{sw}, compared to the preacclimation values. Since the sweat threshold was unchanged, the increase in M_{sw} observed was due to an increase in SSEN, versus earlier onset of sweating.

Frye, A. J., & Kamon, E. (1983). Sweating efficiency in acclimated men and women exercising in humid and dry heat. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 54 (4), 972-977.

Protocol

Four acclimated men ($\dot{V}O_2max = 53.3$ ml·kg^{-1}·min^{-1}) and four acclimated women ($\dot{V}O_2max = 52.6$ ml·kg^{-1}·min^{-1}), who were matched for aerobic capacity and surface area, exercised at 30% $\dot{V}O_2max$ for 3 hr in a hot-humid environment (37/30°C $T_{db/wb}$) and in a hot-dry environment (48/25°C $T_{db/wb}$). Various indices of heat stress and sweat responsiveness were monitored, including HR, T_{re}, $\bar{T}_{sk}$, $\dot{m}_{sw}$ (methacholine technique), regional SGA, and M_{sw}.

Results

The hot-dry test was performed after 13 days of heat exposure; the hot-humid test was performed after 7 days of acclimation. M_{sw} and $\dot{m}_{sw}$ were lower in the hot-humid versus the hot-dry environment in both groups. The lower M_{sw} in the men was achieved by a decrease in SGF whereas in the women, lower M_{sw} was due to a decrease in SGA. In the females, the lower M_{sw} resulted in greater sweating efficiency (Kerslake formula). Thus, in the hot-humid environment,

women conserved body fluids without compromising thermal regulation, evidenced by similar T_{re} between the sexes. The male group had a smaller percent of the maximum number of sweat glands activated in both environments.

Sawka, M., Toner, M., Francesconi, R., & Pandolf, K. (1983). Hypohydration and exercise: Effects of heat acclimation, gender, and environment. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 55 (4), 1147-1153.

Protocol

Six males and six females matched for aerobic power and percent body fat walked on a level treadmill at 80.4 $m \cdot min^{-1}$ for two 50-min sessions separated by a 10 min rest, in three environmental conditions (35°C, 79%; 49°C, 20%; 20°C, 40%; T_{db}, rh). The tests were performed before and after 10 days of acclimation and under two conditions: hypohydration (-5% of baseline body weight) and euhydration.

Results

No significant gender differences in HR, $\bar{T}_{sk}$, or T_{re} were found during any of the tests. The men and women had similar M_{sw} in the comfortable (20°C T_{db}, 40% rh) and the hot-dry (49°C T_{db}, 20% rh) environments. However, the women had lower M_{sw} than the men in the hot-humid (35°C T_{db}, 79% rh) climate.

Wells, C. L. (1980). Responses of physically active and acclimated men and women to exercise in a desert environment. Medicine and Science in Sports and Exercise, 12 (1), 9-13.

Protocol

Five physically active men ($\dot{V}O_2max$ = 49.6 $ml \cdot kg^{-1} \cdot min^{-1}$), and six physically fit women ($\dot{V}O_2max$ = 44.7 $ml \cdot kg^{-1} \cdot min^{-1}$), participated in this study. Each subject alternately rested for 40 min, then exercised at 50% of $\dot{V}O_2max$ for 40 min, for a total of 160 min. The first trial was indoors in a temperate climate (18°C WBGT, 23°C T_{db}), and the second trial was outdoors in a hot-dry environment (29°C WBGT, 39°C T_{db}).

Results

There was no statistical difference between the groups in regards to T_{re}, HR, or $\dot{V}O_2$ throughout either thermal exposure. M_{sw} was greater in the male group than in the female group in the temperate climate but not during the heat exposure. Females had higher $\bar{T}_{sk}$ in the heat than the males. In the heat, $\dot{V}_E$ drift was greater in the women than in the men. The males had higher O_2 pulse values than the females, and the decline in O_2 pulse with exercise in the heat was greater in the women than in the men. The women in this study achieved the same level of thermoregulation as the men, with a lower M_{sw}. Assuming $\bar{T}_{sk}$ largely reflects cutaneous blood flow, the females may have had greater peripheral vasodilation than the men; thus, a larger vasodilation response might account for the higher HR and lower O_2 pulse in the female subjects compared to the male subjects.

SUMMARY TABLE 6
ACCLIMATED FEMALES & MALES AT A RELATIVE WORK RATE

Authors	M/F	Exp Design	Metabolic Rate	Climate Conditions	PV Loss	HS	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Avellini et al. 1980	4/4	180 min	30% VO_2max	36/30 T_{db}°C/rh%				<	=	<	<		$=T_r$
Dill et al. 1977	14/12	60 min	Max Effort	32-47 T_a°C				=	=	=	<		
Frye et al. 1981	4/4	3 hr	30% VO_2max	48/25 $T_{db/wb}$°C			=	=		=		=	$=T_r$
Frye et al. 1983	4/4	3 hr	30% VO_2max	I-37/30				=	=	=	<		
				II-48/25 $T_{db/wb}$°C				=	=	=	=		
Sawka et al. 1983	6/6	50/10 120 min	work/rest 1.34 $m \cdot s^{-1}$	I-35/79					=	=	=	<	
				II-49/20					=	=	=	=	
				III-20/40 T_{db}°C/rh%					=	=	=	=	
Wells et al. 1980	5/6	40/40 160 min	work/rest 50% VO_2max	I-18 WBGT					=		=	<	
				II-29 WBGT					=	>	=	=	

All values are expressed as women compared to men.

Key to symbols
(=) equal to
(>) greater than
(<) less than
(*) Groups were matched for VO_2max

THE EFFECT OF TRAINING ON HEAT TOLERANCE IN WOMEN

Araki, T., Matsushita, K., Umeno, K., Tsujino, A., & Toda, Y. (1981). Effect of physical training on exercise-induced sweating in women. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 51 (6), 1526-1532.

Protocol

Eleven trained and eight sedentary women cycled at various absolute work loads (391, 483, 981, and 1070 kg·min^{-1}) in a hot-humid environment (30°C T_{db}, 60% rh) for up to 2 hr. A subset (n = 3) of the sedentary women were retested after participating in a outdoor summer exercise program, which consisted of running eight km·day^{-1} for 8 weeks.

Results

In the trained group, hidromeiosis was evident at the 1070 and 981 kg·s^{-1} work loads but not at the 483 kg·s^{-1} work load. Compared with the sedentary women, the trained women had lower final T_{re}, $\bar{T}_{sk}$, HR, $\dot{V}O_2$, and earlier onset of sweating when exercising at the same work rate. At identical work loads, the time course of changes in the variables was also different between the two groups. For instance, HR in the trained group increased initially then plateaued regardless of work load, whereas HR rose continuously in the sedentary group. After the sedentary group completed the exercise program, T_{re}, $\bar{T}_{sk}$, HR and $\dot{V}O_2$ were lower during the posttraining HTT (work load = 981 kg·s^{-1}) when compared to the pretraining HTT. In addition, sweat onset was quicker and hidromeiosis was evident after the training program. Because of the study protocol, it was not evident if the observed posttraining improvements were due to an increase in fitness level or to heat acclimatization from outdoor exercise in the summer months.

Buono, M. J., & Sjoholm, N. T. (1988). Effect of physical training on peripheral sweat production. Journal of Applied Physiology, 65 (2), 811-814.

Protocol

Forty young men and women had peripheral sweat production (pilocarpine technique), SGA, and

$\dot{V}O_2max$ measured in a neutral environment. The subjects were divided into four groups based on $\dot{V}O_2max$: (1) fit males ($\dot{V}O_2max$ = 65.9 $ml \cdot kg^{-1} \cdot min^{-1}$), (2) sedentary males ($\dot{V}O_2max$ = 43.8 $ml \cdot kg^{-1} \cdot min^{-1}$), (3) fit females ($\dot{V}O_2max$ = 53.4 $ml \cdot kg^{-1} \cdot min^{-1}$), and (4) sedentary females ($\dot{V}O_2max$ = 37.4 $ml \cdot kg^{-1} \cdot min^{-1}$).

Results

Regional sweat rate was greater in the fit group than in the sedentary group for both sexes. There was no difference in forearm $\dot{m}_{sw}$ between the sedentary men and women or the fit men and women. Both trained and sedentary women had greater SGA than their male counterparts. SGF was greater in the fit groups compared to the sedentary groups. The group of fit males had a greater SGF than the group of fit females. There was no difference in SGF between the male and female sedentary groups. Thus, the women had greater activation of sweat glands, whereas men had larger sweat production per gland. A moderate positive correlation between $\dot{V}O_2max$ and $\dot{m}_{sw}$ was found (r = 0.73).

Drinkwater, B. L., Denton, J. E., Kupprat, I. C., Talag, T. S., & Horvath, S. M. (1976). Aerobic power as a factor in women's response to work in hot environments. Journal of Applied Physiology, 41 (6), 815-821.

Protocol

Six female athletes ($\dot{V}O_2max$ = 48.7 $ml \cdot kg^{-1} \cdot min^{-1}$) and six female nonathletes ($\dot{V}O_2max$ = 39.8 $ml \cdot kg^{-1} \cdot min^{-1}$) walked on a treadmill (work load = 30% $\dot{V}O_2max$) in three thermal environments (28°C T_{db}, 45% rh; 35°C T_{db}, 65% rh; 48°C T_{db}, 10% rh). The exposure limit was 2 hr, consisting of two 50-min exercise sessions interspersed with two 10-min rest periods. Hematocrit, hemoglobin, forearm blood flow, serum ions, serum progesterone and estrogen, and $\dot{Q}$ (acetylene rebreathing) were measured.

Results

Cardiovascular variables were not significantly different between the athletes and nonathletes during the first work period at the two lower temperatures. At 48°C, all of the nonathletes

reached the test termination criteria before completion of the 2-hr test. Additionally, in the hot-dry environment, SV and $\dot{Q}$ were lower in the nonathletes than in the athletes. Forearm blood flow was only higher in the athletes compared to the nonathletes. Athletes had a higher evaporative heat loss during the postexercise recovery period compared to the nonathletes. Selecting a relative work load (30% of $\dot{V}O_2max$) for exercise in the heat did not account for all the thermoregulatory advantages potentiated by training. While physiological variables were similar between the nonathletes and athletes exercising at moderate thermal loads (28°C and 35°C), at a more severe environmental temperature (48°C) differences in cardiovascular responses were clearly apparent between the groups.

Drinkwater, B. L., Kupprat, I. C., Denton, J. E., Horvath, S. M. (1977). Heat tolerance of female distance runners. Annals New York Academy of Sciences, 301, 777-792.

Protocol

Five female marathoners ($\dot{V}O_2max = 56.3\ ml \cdot kg^{-1} \cdot min^{-1}$) and five control females ($\dot{V}O_2max = 40.4\ ml \cdot kg^{-1} \cdot min^{-1}$), who were matched for age and body surface area, twice alternated rest for 10 min with exercise at 30% $\dot{V}O_2max$ for 50 min in a hot-dry environment (48°C T_{db}, 10% rh).

Results

Only one control female was able to complete the second 50 min walk; therefore, comparisons between the groups were made only through the second recovery period. Although the athletes were performing more work than the controls, their HR, T_{re}, and $\bar{T}_{sk}$ were less than those of the controls'. Also, this greater work rate potentiated a larger metabolic load for the athletes than the controls (159 vs. 134 $kcal \cdot m^{-2} \cdot h^{-1}$); however, E was only slightly greater in the athletes than the controls (226 vs. 189 $kcal \cdot m^{-2} \cdot h^{-1}$). The athletes had less cardiovascular strain during the HTT than the controls, evidenced by the lower HR (18%), higher SV (32%) and higher $\dot{Q}$ (17%) in the athletes. The athletes began the test with 26% greater blood volume than the controls, and lost less PV during the heat exposure (2.9% vs. 5.8%). Thus, during the first recovery period, athletes had 28% greater PV than the controls.

Fortney, S., & Senay, L. (1979). Effect of training and heat acclimation on exercise responses of sedentary females. Journal of Applied Physiology: Respiration, Environment, Exercise Physiology, 47 (5), 978-984.

Protocol

Nine women ($\dot{V}O_2max$ = 37.9 ml·kg^{-1}·min^{-1}) pedaled an ergometer at 40% of $\dot{V}O_2max$ for 45 min in a cool (16°C to 20°C T_{db}, 30% rh) and a hot-dry (45°C T_{db}, 30% rh) environment. The tests were completed before and after 4 weeks of physical training, and again after 14 days of heat acclimation. The women performed the pretest twice, at pre- and postovulatory phases of their menstrual cycle.

Results

During the pretest there were no differences in any of the parameters measured between the pre- and postovulatory tests. The exercise program potentiated increases in $\dot{V}O_2max$ (15%), PV (9.7%), plasma protein (11.7%), and various plasma ions (13% to 16%). Due to the PV expansion, concentrations of plasma proteins and ions were not altered. Red blood cell volume and total body water did not change after training. HR and $\bar{T}_{sk}$ during the tests were lower after the training program compared to before the training. T_{re}, M_{sw}, and SSEN did not change as a result of the physical training program. Acclimation served to maintain the expanded PV. In addition, K^+ concentration increased after acclimation compared to posttraining values. Acclimation potentiated a decrease in T_{re} and a further decline in HR compared to posttraining exercise tests. Hemoconcentration occurred during all test sessions. There was a net loss of water and ions (except K^+). The relatively larger loss of water over electrolytes increased plasma osmolarity. Plasma protein concentration increased primarily due to the loss of PV.

Gisolfi, C. V., & Cohen, J. S. (1979). Relationships among training, heat acclimation, and heat tolerance in men and women: The controversy revisited. Medicine and Science in Sports and Exercise, 11 (1), 56-59.

Protocol

Six women underwent three heat tolerance tests, consisting of a treadmill walk at 30% $\dot{V}O_2max$ in a hot environment (45/24°C $T_{db/wb}$) for up to 4 hr. After the first test, the women completed an 11-week interval training program. Each exercise session consisted of 90 seconds of treadmill running (10 to 13 km·hr^{-1}), followed by 30 seconds of rest. This pattern continued for 50 to 60 min. The intensity of the workouts increased over time, eliciting heart rates that were 90% to 95% of maximal values. After completion of the training program a second HTT was performed. Subsequent to the posttraining HTT, the women completed 7 days of an acclimation program consisting of walking on a treadmill at 30% of $\dot{V}O_2max$ in a hot environment (45/24°C $T_{db/wb}$). Following completion of the acclimation protocol a third HTT was performed.

Results

During the first HTT none of the women walked longer than 2.5 hr. After 11 weeks of training, physiological strain during the second HTT was reduced: four of six women completed the 4-hr test, and final values for HR, T_{re}, and $\bar{T}_{sk}$, all declined substantially. After acclimation, there was no difference in the physiological responses of the women to the third HTT compared to posttraining HTT. Thus, acclimation conferred no further thermoregulatory benefits to the trained women.

Kobayashi, Y., Ando, Y., Okuda, N., Takaba, S., & Ohara, K. (1980). Effects of endurance training on thermoregulation in females. Medicine and Science in Sports and Exercise, 12 (5), 361-364.

Protocol

Eleven female athletes ($\dot{V}O_2max$ = 48.2 ml·kg^{-1}·min^{-1}), eight female nonathletes ($\dot{V}O_2max$ = 38.4 ml·kg^{-1}·min^{-1}) and eight male nonathletes ($\dot{V}O_2max$ = 44.1 ml·kg^{-1}·min^{-1}) sat in a warm environment (32°C T_{db}, 40% rh) with their lower legs immersed in a hot water bath (42°C) for 2 hr.

Results

From 30 to 120 min, T_{re} was significantly lower in the athletes than both groups of nonathletes. $\dot{m}_{sw}$ was less for the female nonathletes than for both the male nonathletes and the female athletes. $\dot{m}_{sw}$ in the female athletes, although greater, was not significantly different from $\dot{m}_{sw}$ in the male nonathletes. It was found that the SSEN for the males was greater than for either group of females. SSEN was not different between the groups of females. However, in the female athletes, sweat onset occurred at a lower T_{re} compared to both the female and male nonathletes. Additionally, final HR was lower in the athletes than in the nonathletes of either sex.

Lamont, L. S. (1987). Sweat lactate secretion during exercise in relation to women's aerobic ability. Journal of Applied Physiology, 62 (1), 194-198.

Protocol

Five active ($\dot{V}O_2max$ = 51.2 $ml \cdot kg^{-1} \cdot min^{-1}$) and five sedentary ($\dot{V}O_2max$ = 41.0 $ml \cdot kg^{-1} \cdot min^{-1}$) women exercised on a cycle ergometer at 70% of their $\dot{V}O_2max$ for 60 min in a thermal neutral environment (17 to 21/11 to 21°C $T_{db/wb}$).

Results

The sedentary group had a lower M_{sw}, a smaller drop in PV, but an elevated sweat lactate concentration compared to the active group. Data analysis indicated that M_{sw} and lactate concentration in sweat were shown to have a moderate negative correlation (r = -0.79). However during exercise, peak blood lactate values from both sedentary and active groups were not related to lactate concentration in sweat (r = 0.02).

SUMMARY TABLE 7:
THE EFFECT OF TRAINING ON HEAT TOLERANCE IN WOMEN

Authors	M/F	Exp Design	Metabolic Rate	Climate Conditions	PV Loss	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Araki et al. 1981	11/8	120 min	ex varying	30/60 T_{db}°C/rh%			>	>	>			>Time
Buono et al. 1988	21/21	Pilocarpine	Stimulated	Sweating	Fit Sed					= =		
Drinkwater et al. 1976	6/6	50/10 120 min	ex 30% VO_2max	I-25/45 II-35/65 III-48/10 T_{db}°C/rh%		<			= =			
Drinkwater et al. 1977	5/5	10/50 120 min	rest/ex 30%VO_2max	48/10 T_{db}°C/rh%			>	>	>	>		
Fortney et al. 1979	0/9	4 week PT 45 min	40%VO_2max	45/30 T_{db}°C/rh%			=	>	>	=	=	
Gislofi et al. 1979	0/6	11 week PT 4 hr	30%VO_2max	45/24 $T_{db/wb}$°C		<	>	>	>			
Kobayashi et al. 1980	11/8	120 min	rest	legs in hot water bath		>		>	<	=		>T_r
Lamont et al. 1987	5/5	60 min	70%VO_2max	neutral	<					<		

All values are expressed as sedentary compared to active participants.

Key to symbols:
(=) equal to
(>) greater than
(<) less than
(PT) Physical Training

INFLUENCE OF SEX HORMONES ON THERMOREGULATION IN WOMEN

Bittel, J., & Henane, R. (1975). Comparison of thermal exchanges in men and women under neutral and hot conditions. Journal of Physiology, 250, 475-489.

Protocol

Unacclimated subjects, nine men and five women, completed a HTT consisting of 90 min in a neutral environment (30/23°C $T_{db/wb}$), and 90 to 120 min of incremental heating (rate = 6°C $\cdot min^{-1}$). The women were tested in both the pre- and postovulatory phases of their menstrual cycle (determined by oral temperature). T_{re}, M_{sw}, and $\bar{T}_{sk}$ were measured.

Results

In the neutral environment, $\bar{T}_{sk}$ was lower and T_{re} was higher in the postovulatory women compared to the preovulatory women. Skin conductance was higher in both the pre- and postovulatory women compared to the men. No other significant differences between the groups existed. During incremental heating, final T_{re} and final $\bar{T}_{sk}$ were lower in the men versus the pre- and postovulatory women. The time delay before sweat onset was significantly longer in the postovulatory women compared to the preovulatory women and the men. SSEN for the women in both phases of the menstrual cycle was significantly lower than SSEN for the men. The longer delay in sweat onset and the lower SSEN in the postovulatory women resulted in a greater body heat storage for this group (5.8 $kj \cdot kg^{-1}$) compared to the preovulatory women (3.6 $kj \cdot kg^{-1}$) and the men (4.0 $kj \cdot kg^{-1}$). Skin conductance and M_{sw} were not different between the pre- and postovulatory women, therefore these variables were not responsible for the differences in HS observed between these groups. The only difference observed between the pre- and postovulatory groups was a longer delay in sweat onset. It is likely that the longer delay in sweat onset for the postovulatory women potentiated the greater HS.

Carpenter, A. J., & Nunneley, S. A. (1988). Endogenous hormones subtly alter women's response to heat stress. Journal of Applied Physiology, 65 (5), 2313-2317.

Protocol

Eight heat acclimated women ($\dot{V}O_2max$ = 39.1 $ml \cdot kg^{-1} \cdot min^{-1}$) performed a HTT consisting of 2 hr of cycle ergometry at 30% of $\dot{V}O_2max$ in a hot-dry environment (48/25°C $T_{db/wb}$) during menstrual, pre- and postovulatory phases of their menstrual cycles (determined by hormonal analysis). During acclimation, the women completed the HTT on consecutive days until steady state T_{re} and HR was achieved in the second hour of testing on two consecutive days (range = 3 to 7 days). When time elapsed between test days (due to time between menstrual cycle phases), exposures were added on alternate days to maintain acclimation. Physiological variables measured include, HR, T_{re}, M_{sw}, and $\dot{V}O_2$.

Results

Initial T_{re} was highest in the luteal group and lowest in the ovulatory group. The pattern of T_{re} luteal > T_{re} flow > T_{re} ovulatory continued during the exercise bout. $\bar{T}_{sk}$ exhibited the same hierarchy with phase as did T_{re}; however, none of the differences reached statistical significance. There was no difference in M_{sw} between trials at the different phases of the menstrual cycle.

Frascarolo, P., Schutz, Y., & Jéquier, E. (1992). Influence of the menstrual cycle on the sweating response measured by direct calorimetry in women exposed to warm environmental conditions. European Journal of Applied Physiology, 64, 449-454.

Protocol

Eight women sat in a neutral environment (28°C T_{db}, 40% rh) for 30 min, then rested in a warm environment (35°C T_{db}, 40% rh) for 90 min during the luteal and follicular phases of their menstrual cycle (determined by hormonal analysis). T_{ty}, $\bar{T}_{sk}$, $\dot{V}O_2$, and dry heat loss were measured over time.

Results

In the neutral environment, T_{ty} was higher during the luteal test than the follicular test, but $\bar{T}_{sk}$ was not different between the two tests. In the warm environment, the time delay before sweat onset, rise in T_{ty}, rise in $\bar{T}_{sk}$, H, total heat loss, and BHC did not exhibit a menstrual cycle effect.

The only difference detected was a higher T_{ty} at sweat onset during the luteal test compared to the follicular test.

Frye, A. J., Kamon, E., & Webb, M. (1982). Responses of menstrual women, amenorrheal women, and men to exercise in a hot, dry environment. European Journal of Applied Physiology, 48, 279-288.

Protocol

Four menstruating women, four amenorrheal women, and four males, all with similar aerobic capabilities, walked on a treadmill at 25% to 30% of $\dot{V}O_2max$ in a hot-dry environment (48/25°C $T_{db/wb}$) for up to 3 hr. The test was repeated after 8 to 10 days of acclimation. The acclimation protocol was the same as the test protocol, but the duration was only 2 hr. The menstruating women completed the pre- and postacclimation tests during both the pre- and postovulatory phases of their menstrual cycle (determined by change in basal temperature).

Results

During the preacclimation testing, after the first hour, T_{re} was higher in the groups of women than in the men. In addition, the rate of HS was higher in the menstrual and amenorrheal women than in the men. The T_{re} at sweat onset was not different between the groups, but the men showed a greater M_{sw} than the women. Thus, a lower sweat rate, not a delay in sweat onset, was associated with the greater HS in the females compared to the males. In this dry environment, E_{max} is large, and a greater M_{sw} may allow for more E. Thus the lower T_{re} in the men, may have been potentiated by greater E, due to their greater M_{sw}. M_{sw} was not different between the preovulatory, postovulatory, or amenorrheal women. Acclimation eliminated the gender difference in T_{re} and M_{sw} observed in the pretest.

Haslag, W. M., & Hertzman, A. B. (1965). Temperature regulation in young women. Journal of Applied Physiology, 20 (6), 1283-1288.

Protocol

In Protocol I, the thermal responses of five men and three women to rising chamber temperature were examined. In Protocol I, the thermal environment consisted of: (1) 1-hr exposure at 25°C, (2) increasing temperature ($6.6°C \cdot hr^{-1}$) to 45°C, then (3) temperature maintenance for one additional hour. Results from this study were compared to thermoregulatory variables of three other women participating in Protocol II. In Protocol II, three women were exposed to a constant thermal environment of 43.3°C for 3 hr. The women in each study were tested during the menstrual, preovulatory and postovulatory phases of their menstrual cycle (phases determined by self-report).

Results

For protocol I, the only differences between the male group and the female groups was a higher oral temperature throughout the entire chamber exposure in the postovulatory phase group of women. Additionally, at any given T_{or}, $\dot{m}_{sw}$ was diminished in the postovulatory group.

During protocol II, the T_{or} and $\bar{T}_{sk}$ were greater when the women were in the postovulatory versus preovulatory or menstrual phase of their cycle. There was no influence of menstrual cycle phase on $\dot{m}_{sw}$ or cutaneous blood flow.

Horvath, S. M., & Drinkwater, B. L. (1982). Thermoregulation and the menstrual cycle. Aviation Space and Environmental Medicine, 53 (8), 790-794.

Protocol

Four women ($\dot{V}O_2max$ = 39.0 $ml \cdot kg^{-1} \cdot min^{-1}$) completed nine HTTs consisting of two 50/10 min work/rest cycles (work load = 30% $\dot{V}O_2max$). The HTTs were completed in three environmental conditions: neutral (28°C T_{db}, 13 mmHg P_{H2O}), warm-humid (35°C T_{db}, 28 mmHg P_{H2O}), and hot-dry (48°C T_{db}, 8.7 mmHg P_{H2O}). The tests in each climate were completed once at each of three phases of the menstrual cycle (determined by hormonal analysis): ovulation, luteal, and flow. Measured physiological responses included $\bar{T}_{sk}$, T_{re}, HR, $\dot{V}O_2$, $\dot{Q}$, E, M_{sw}, PV, and forearm blood flow.

Results

The hormonal definition of ovulation, high estradiol and low progesterone, was achieved only for the warm-humid condition. Therefore, at the neutral and hot-dry environments, comparisons were between luteal and flow phases only. During the initial rest period, in the neutral environment, T_{re} was higher in the luteal phase group than in the menstrual phase group. This difference in T_{re} vanished after onset of exercise. $\bar{T}_{sk}$ was lower during exercise and recovery in the luteal phase group compared to the menstrual phase group. In the recovery portion of the test, forearm blood flow was also lower for the women in the luteal phase of their cycles than when they were in the flow phase. During the rest period, in the warm-humid environment, T_{re} was higher for the women in the luteal versus ovulatory or flow phases of their menstrual cycles. This difference persisted into the 25th minute of the exercise bout; however, final T_{re} was not different between the groups. During both the rest and recovery periods of the test, SV was higher in menstruating women than in women at the ovulatory or luteal phase of their cycles. During the hot-dry test, no participant completed the 2-hr test; however, there were no differences in stay time between the phases. In addition, the marked increase in T_{re} and HR were unrelated to cycle phase. Women in the luteal phase of their cycles had a greater E and a larger percent drop in PV than when they were in the flow phase of their cycles.

Kolka, M. A., & Stephenson, L. A. (1989). Control of sweating during the human menstrual cycle. European Journal of Applied Physiology, 58, 890-895.

Protocol

Seven unacclimated women ($\dot{V}O_2max$ = 43.7 $ml \cdot kg^{-1} \cdot min^{-1}$) participated in three distinct test protocols during the follicular and luteal phases of their menstrual cycle (determined by change in basal body temperature). In Protocol I, the women exercised on a cycle ergometer at 80% of $\dot{V}O_2max$ in a hot-dry environment (50°C T_{db}, 14% rh) until T_{es} rose 0.8°C to 1.0°C. In Protocol II, the women rested in the hot-dry environment for up to 3 hr. In Protocol III, after 20 min of rest, the women exercised at 85% of $\dot{V}O_2max$ on a cycle ergometer for 35 min in a warm environment (35°C T_{db}, 25% rh). Physiological variables measured included T_{es}, $\bar{T}_{sk}$, $\dot{m}_{sw}$, HR, and H.

Results

For protocol I, the mean stay time was 9 min and was not different between the groups. T_{es} at sweat onset was lower in the women who were in the follicular versus the luteal phase of their cycles. However, SSEN was similar between the phases. Final $\bar{T}_{sk}$ was higher in the luteal phase group than the follicular phase group. For Protocol II, the average stay time was 3 hr and was not different between the groups. The differences observed between the groups in Protocol I persisted in this passive heating protocol. For Protocol III, T_{es} at sweat onset was lower in the follicular phase group than in the luteal phase group. SSEN was similar between the groups.

Senay, L. C., Jr. (1973). Body fluids and temperature responses of heat-exposed women before and after ovulation with and without rehydration. Journal of Physiology, 232, 209-219.

Protocol

Four unacclimated sedentary women rested in a hot environment (43/29°C $T_{db/wb}$) for 10 hr. Tests were performed during pre- and postovulatory phases of two menstrual cycles. While performing the tests during one menstrual cycle the subjects were allowed to rehydrate; during the tests of the other cycle, the subjects were allowed to progressively dehydrate.

Results

During the rehydration tests, there was a significant decrease in plasma osmolarity, but no significant decreases in the concentration of K^+, Na^+, or Cl^- were found. However, the sum of the declines in concentration for these three ions was equivalent to the change in plasma osmolarity. During the dehydration tests, all measured plasma constituents increased in concentration. Plasma protein increased due to both a loss in PV and to an increase in total circulating protein. M_{sw} was lower in the dehydration test compared to the rehydration test. There was no difference in M_{sw} between the pre- and postovulatory tests. During the dehydration test, increase in T_{or} in the postovulatory group was less than the increase in T_{or} in the preovulatory group. Although basal T_{or} was higher in the postovulatory group, sweat onset occurred at a similar T_{or} for the pre- and postovulatory groups. The change in plasma protein concentration was similar between the groups. However, globulin fraction values increased to

a greater extent in the preovulatory than in the postovulatory group; whereas, albumin fraction values increased to a greater extent in the postovulatory than in the preovulatory group. Compared to results of a similar study of men, the women lost equivalent amounts of body weight. However, the women experienced no immediate hemodilution and had a loss in PV 1.5 times the rate at which the men lost PV. The difference in rate of change in PV was not accompanied by a difference in percent change in plasma protein concentration between the male and female subjects. Thus, greater preservation of PV in the men was not accomplished by an increase in oncotic pressure compared to the women.

Stephenson, L., & Kolka, M. (1988). Plasma volume during heat stress and exercise in women. European Journal of Applied Physiology, 57, 373-381.

Protocol

Five women ($\dot{V}O_2max$ = 38.3 $ml \cdot kg^{-1} \cdot min^{-1}$) completed four tests in a hot environment (50°C T_{db}, 16 mmHg P_{H2O}). Two of the tests consisted of resting on a reclined cycle ergometer until T_{es} rose 0.8°C (approximately 167 min). The other two tests consisted of pedaling a reclined cycle ergometer (80% $\dot{V}O_2max$) until T_{es} rose 0.8°C (approximately 9 min). The women performed both protocols during the luteal and follicular phases of their menstrual cycles (determined by change in T_{or}).

Results

At rest, T_{es} was higher for the women in the luteal versus follicular phase of their menstrual cycles. PV and total circulating protein were greater for the women in the follicular phase compared to the luteal phase of their menstrual cycles. The concentrations of plasma protein, Na^+, and K^+ in plasma were not different between the two menstrual cycle phases. During the passive heating, metabolic rate was not changed in either phase of the menstrual cycle or by heat exposure. On the other hand, PV was influenced by both phase and exposure. Plasma volume decreased during the test; the PV lost was 170 ml (-5%) in the follicular phase and 300 ml (-11%) in the luteal phase. Plasma protein and Na^+ concentrations increased during the heat exposure with no differences between menstrual cycle phases. Total circulating protein did not

change during passive heating in either menstrual phase. For the exercise protocol, PV decreased in both groups; the PV loss was 470 ml (-15.8%) in the follicular, and 380 ml (-13.3%) in the luteal phase groups. Concentrations of plasma protein, Na^+, and K^+ increased in both groups of women, showing no phase effect. Likewise, total circulating protein was elevated but not different between the groups.

Stephenson, L. A., & Kolka, M. A. (1985). Menstrual cycle phase and time of day alter reference signal controlling arm blood flow and sweating. American Journal of Physiology, 249 (18), R186-R191.

Protocol

Four women rested for 30 min then exercised for 30 min at 60% of $\dot{V}O_2max$ in a hot environment (35°C T_{db}, 17 mmHg P_{H2O}) at 0400 and 1600 hours during the follicular and luteal phase of the menstrual cycle. T_{es}, forearm blood flow, forearm $\dot{m}_{sw}$, $\bar{T}_{sk}$, and plasma catecholamines were measured.

Results

HR at rest was higher in the luteal phase test compared to the follicular phase test. However, exercise HR showed no menstrual phase effect. At rest, T_{es} was higher in the luteal versus the follicular phase test. Initiation of cutaneous vasodilation occurred at a higher T_{es} during luteal testing versus follicular testing. T_{es} threshold for sweat onset was lower during the follicular session compared with the luteal session only during the 0400 time period. SSEN was unaffected by menstrual phase. HR response at rest was similar between the 0400 and 1600 tests, but HR during exercise was higher during the 1600 compared to the 0400 test. T_{es} at rest was higher in the 1600 versus the 0400 tests. In addition, the T_{es} threshold at onset of cutaneous vasodilation and initiation of sweating was higher in the 1600 test compared to the 0400 test. However, SSEN was not influenced by time of day.

Wells, C. L., & Horvath, S. M. (1973). Heat stress responses related to the menstrual cycle. Journal of Applied Physiology, 35 (1), 1-5.

Protocol

Seven women rested in a hot environment (48°C T_{db}, 11 mmHg P_{H2O}) for 2 hr during three menstrual phases. Ovulation, luteal, and menstruation phases were identified on the basis of daily body temperature changes. During the test HR, T_{re}, M_{sw}, $\dot{V}_B$, $\dot{V}O_2$, and ion concentration in sweat were monitored. Blood constituents were measured pre- and postheat exposure.

Results

No difference attributed to menstrual cycle was detected in T_{re}, $\bar{T}_{sk}$, $\bar{T}_b$, $\dot{V}_E$, $\dot{V}O_2$, HR, M_{sw}, E, or serum concentrations of Na^+ and K^+. However, a tendency for lower T_{re} and HR during menstruation compared to the other phases was revealed. Basal hemoglobin and hematocrit values were lower and serum Cl^- concentration was higher during menstruation than during ovulation. Basal hemoglobin values were higher during the ovulatory than the luteal phase. Postheat exposure electrolyte loss in sweat was different for the three phases. Na^+ and Cl^- losses were greater in the ovulatory versus luteal phase. Also, plasma Na^+ loss due to sweating was greater during menstrual flow than during the luteal phase.

SUMMARY TABLE 8:
INFLUENCE OF SEX HORMONES ON THERMOREGULATION IN WOMEN

Authors	n	Exp Design	Metabolic Rate	Climate Conditions	Men Phase	PV Loss	HS	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Bittel	5	+6°C/min	rest	30/23°C	PO		>					=		>Time
et al. 1975		210 min		$T_{db/wb}$	F									
Carpenter	8	120 min	30%	48/25°C	PO			=	=	=		=		
et al. 1988			VO_2max	$T_{db/wb}$	F			=	>	>		=		
Frascarolo	8	90 min	rest	35°C/40%	PO	=	=		=	=			=	$>T_{ty}$
et al. 1992				T_{db}/rh										
Frye	4	Unacclim	30%	48/25°C	PO				=			=	=	
et al. 1982			VO_2max	$T_{db/wb}$	Amen				=			=		=
	4	Acclim	30%		PO			=			=		=	
			VO_2max		Amen				=			=		=
Haslag	3	150 min	rest	I-25to45°C	PO								<	
et al. 1965		180 min	rest	II-43.3°C	PO			>	>	>	=			
				T_a										
Horvath	4	10/50 min	rest/ex	48°C/9mmHg	PO	=+		=	=	=	=	=+		
et al. 1982			30%	35°C/28mmHg	F	=		=	=	=	=	=		
	4	120 min	VO_2max	T_{db}/P_{H2O}	PO	=		=	=	=	=	=		
					F	=		=	=	=	=	=		

Key to abbreviations (PO) Postovulation
(F) Menstrual Flow
(Amen) Amenhorria
(Men) Menstrual

Key to symbols (=) equal to preovulatory
(>) greater than preovulatory
(<) less than preovulatory
(+) greater than flow

SUMMARY TABLE 8 CONTINUED: INFLUENCE OF SEX HORMONES ON THERMOREGULATION IN WOMEN

Authors	n	Exp Design	Metabolic Rate	Climate Conditions	Men Phase	PV Loss	HS	Stay Time	Core Temp	Tsk	HR	SR	SSEN	Sweat Onset
Kolka	7	I-T_{es} rise	I-80% VO_2max	I-50°C/14%	PO			=		>			=	>T_{es}
et al. 1989		II-180 min	II-rest	II-50°C/14%	PO			=	>	>	=	=	=	>T_{es}
		III-35 min	III-85% VO_2max	III-35°C/25% T_{db}/rh	PO			=	>	=	=	=	=	>T_{es}
Senay et al.	4	10 hr	rest	43/29°C $T_{db/wb}$	PO							=		=
Stephenson	5	I-167 min	rest	50°C/1.6mmHg	PO		>							
et al. 1988		II-9 min	80% VO_2max	T_{db}/P_{H2O}	PO		<							
Stephenson	4	30 min	rest	35°C/1.7mmHg	PO			=			>	=	=	
et al. 1985		30 min	60% VO_2max	T_{db}/P_{H2O}	PO						=		=	>T_{es}
Wells et al. 1973	7	120 min	rest	48°C/11mmHg T_{db}/P_{H2O}	PO				=		=	=	=	

Key to abbreviations
(PO) Postovulation
(F) Menstrual Flow
(Men) Menstrual

Key to symbols
(=) equal to preovualtory
(>) greater than preovulatory
(<) less than preovulatory
(+) greater than flow

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this technical report is to provide an overview of the literature on the similarities and differences between men and women in their physiological responses to heat stress. Studies that compare thermoregulation in physically fit and sedentary females, as well as research examining the effect of the menstrual cycle on thermal physiology, are included. For each study reviewed, a brief synopsis of the methodology and a summary of relevant results are provided. It was the intent of this report to provide a literature resource, not a review paper, regarding gender differences in thermoregulation during heat exposure.

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